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6. AUTHOR(S) Deborah J. Goodings		
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13. ABSTRACT (Maximum 200 words)

DAAH 049610034:

Research Problem 1: Frost heave and thaw induced settlement in silt and silty clay developing over a year have been modelled correctly using a geotechnical centrifuge with tests requiring less than a day. In these tests, freezing model tests in clay have been conducted. Experimental results indicate the following: freezing regime influences depth of freezing, magnitude of heave, and characteristics of the ice; specimen preparation affects heave only through its effect on water content; position of the phreatic surface has little effect on heave in saturated clay; there appear to be scale effects, in terms of the nature of the ice formed in 35g (1:35 scale) models vs 55g (1:55g) models. These characteristics differ from those for freezing in silt where smaller water content and greater permeability lead to greater depth of freezing and greater heave.

Research Problem 2: Capping contaminated sediments with clean sediments has been used by the US Army to reduce the environmental impact of the contaminated sediments. Preliminary tests to assess the possibility of contaminant breakthrough occurring through the clean sediment cap are complete. The use of rapid centrifuge model tests to model long term effects in the field was considered.

DAAG 559810066:

Upgrades to the University of Maryland centrifuge facility are completed. The upgrades include purchase, installation, and integration of a much improved data acquisition system, inflight camera capabilities, cone penetrometer testing apparatus, increased slip rings and fluid rotary ports.

14. SUBJECT TERMS			15. NUMBER OF PAGES
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34816-EV 38146-EV

CONTRACT/GRANT NUMBER: DAAH-049-610034 and DAAG-55-98-10066

REPORT TITLE: Final Report for 1. Centrifuge Modelling of Two Civil-Environmental Problems, and 2. DURIP: Enhancement of Geotechnical Centrifuge Facility

is forwarded for your information.

SUBMITTED FOR PUBLICATION TO (applicable only if report is manuscript):

Sincerely,
Deborah J. Goodings

Final Report to ARO for:
DAAH-049-610034 – Centrifuge Modelling of 2 Civil/Environmental Problems
DAAG-55-98-10066- DURIP – Enhancement of Geotechnical Centrifuge Facility

1. Manuscripts published or submitted under ARO sponsorship;

S.J. Han, D.J. Goodings, A. Torrents, M. Zeinali and J. Robinson (1998), "A Contaminant Released in Freezing Ground," Proc. of International Society of Soil Mechanics and Geotechnical Engineers, September '98 Conference, Tokyo, A.A. Balkema, Netherlands pp. 601- 605.

S.J. Han, D.J. Goodings, A. Torrents, M. Zeinali, (1999) "Underground Leakage into Frozen Ground" ASCE Journal of Cold Regions Engineering, Volume 13, No.2, June, pp103-112

D.J. Goodings, (1999) "An Examination of Rapid Centrifuge Physical Modelling Studies of Contaminant Movement in Freezing Soil," Polar Record Journal, volume 35(192), pp 11-18.

M. Zeinali, D.J. Goodings, A. Torrents, "Fate and Transport of Pollutants in Freezing Soil and the Application of Geoenvironmental Centrifuge Physical Modelling", under review by Polar Record Journal

2. a) Scientific Personnel Supported:

Undergraduates (through AASERT program):
David Wong
Jeff Basford
William Greene
Jennifer Robinson

PhD Graduate Students:
Sang Joon Han
Mazyar Zenali

Faculty:
Deborah J. Goodings - Professor & PI
Alba Torrents – Associate Professor

b) Honors/Awards/Degrees Granted:

PhD's to Han and Zenali expected in 2002.

3. Inventions: None

4. Scientific Progress:

DAAH-049-610034:
Research Problem 1 - Freezing Effects in Clay:
The major portion of DAAH049610034 involved centrifuge modelling of frost heave in clay. That research had two goals:

- To investigate the correctness of centrifuge modelling for simulating full scale frost heave in clay using the same technique used in earlier research for silt (DAAH0493G0023), but this time investigating response of one factory processed kaolin clay and one naturally occurring clay.

- To investigate the effects on frost heave of various site conditions, including the position of the phreatic surface; the method of soil preparation; and the freezing regime applied.

At the completion of this funding period, the proposed research remains incomplete, however funding from other sources will continue to support the primary research student (S.J.Han) and his remaining minor laboratory expenses, which will be complete in summer 2002. Copies of all reports, articles, and dissertations resulting from that work will be made available to ARO for distribution when the research is complete. It is worth noting that the substantial delays in the Ph.D. student's research progress were a direct result of his need to upgrade the temperature control system compatible with the new centrifuge data acquisition system funded through DURIP grant (DAAG559810066). The improvement in temperature control and data acquisition has been very substantial, however a result was considerable unanticipated delay in research progress.

Thirty-three centrifuge model tests have been completed simulating heave developing in a 4m high column of factory produced kaolin. Tests have examined the effects on freezing response of:

i) Two temperature regimes
- step freezing in which upper and lower boundary temperatures are changed abruptly from +3°C throughout, to - 3°C on the upper boundary and +1°C on the lower boundary
- ramp freezing in which upper and lower boundary temperatures are changed slowly from +3°C throughout, achieving simulation of a 3 month steady decline from +3°C throughout to - 3°C on the upper boundary, and from +3°C to +1°C on the lower boundary; this was followed by a 3 month constant temperature winter.

ii) Differences in specimen preparation, including different water contents and different consolidation histories

iii) Differences in elevation of the phreatic surface

iv) Differences in model scale

The preliminary conclusions are as follow:

i) The freezing regime has the following effects:
- The magnitude of heave in a step frozen model is less than that in a ramp frozen model even when freezing degree days applied are equal, and target boundary temperatures are equal
- The depth of freezing in a step frozen model is less than that in a ramp frozen model even when freezing degree days applied are equal and target boundary temperatures are equal
- The characteristics of ice in step frozen models are different than in ramp frozen models:
    * Step frozen models show ice lenses that increase in thickness with increasing depth in the frozen zone, and with orientation becoming more horizontal with depth
    * Ramp frozen models show ice lenses with similar size throughout the frozen zone, and appear to be consistently horizontal in orientation at all depths
    * Variations in the bottom boundary temperature imposed (at depth 4m), at least within the range of these experiments, has no measurable influence on the freezing event, because it is so far removed from the freezing zone for the freezing periods tested

ii) Specimen preparation, including both initial water content, as well as consolidation history, influences frost heave directly by governing how much water is available in the freezing process. There do not appear to be other, stress related effects. All specimens were saturated.

iii) The low permeability of clay, the initial water content of the saturated soil, and the rate at which the freezing front advances dominate frost heave by controlling water movement in the immediate vicinity of the freezing soil. For saturated clay, the location of the phreatic surface appears not to be very important in development of heave, as the low permeability of the clay prevents supply of water from any great depth below the freezing soil, unlike the case of silt undergoing freezing.

iv) Effects of scale have been less easy to identify. There appears to be some scale effect in the formation of the ice, based on visual inspection. In 1:35 (35g) ramp frozen models, a cake of ice forms on the soil surface, and ice lenses formed below are easily identified as lenses. Below the lenses, the soil is cold but without evidence of lenses, having a consistency resembling smoothly frozen ice cream. This consistency is attributed to a combination of cooling induced consolidation due to negative water pressures developing in advance of the freezing front, and stiffening arising from the beginning of freezing itself, but before ice lenses can form. In contrast, in 1:45 (45g) and 1:55 (55g) scale models, in which the depth of freezing is less (as expected), a cake of ice forms on the soil surface, but the zone of ice lenses is not observed, transitioning instead directly to the "ice cream" like consistency. These observations are in contrast to observations of ice formation in centrifuge models of silt (by Yang and Goodings, 1998), in which models showed evidence of similar development of ice in all models at 1:20 (20g), 1:30 (30g), 1:45 (45g), with dimensions of ice formations roughly to scale.

The tests planned for the remaining period of research will examine the following:

i) Freezing characteristics in Fort Edwards clay, a natural silty clay with some sand, that is well characterized by the US Army Cold Regions Research and Engineering Lab, and has been provided by them to us
ii) Continuing examination of scale effects in both soils — there is a possibility that scale effects may be a problem in the 100% kaolin clay, but not in the natural silty clay, because of differences in soil composition
iii) Freezing characteristics developing from a long freezing period (extending beyond a winter of freezing)
iv) Freezing under different temperature gradients – ramped, but much colder, for example.

During the early stages of this research there was a period when control of model boundary temperatures was not accurate enough for the research proposed. That time was used to conduct a small suite of tests to examine the paths followed when a contaminant was released underground into freezing or frozen soil. The path of ethylene glycol (antifreeze) injected below

ground into a leaking reservoir installed in silt before, during or after freezing at the depth of the leak was identified, and contrasted in one case to the path followed by a water leak of the same temperature. When ethylene glycol was injected before any freezing, subsequent freezing drew the contaminant vertically to the soil surface. When it was injected after freezing had penetrated well past the leak, it was contained, at least over that duration, by the surrounding ice rich frozen soil. When it was injected as freezing was occurring at the level of the leak, its path was long and inclined upward, moving far from the point of injection. Water injected similarly during freezing did not travel far from the point of injection before being frozen into place.

Research Problem 2 - Modelling Dioxin Expulsion from Contaminated Subaqueous Sediments

Capping has been considered as a method to isolate dioxin contaminated subaqueous sediments from the water column. A prime concern in that evaluation is the possible expulsion of contaminant either during or subsequent to the capping. The research conducted here was aimed at estimating the time of flux and breakthrough of contaminants. For hydrophobic organic pollutants such as dioxin, the organic matter content of the sediment and of the capping material were the most important parameters controlling breakthrough and the time to steady state equilibrium.

We performed batch experiments with pentachlorophenol and with arsenic. The contaminated material was equilibrated with a solution containing organic matter concentrations ranging from 0 to approximately 9ppm organic carbon (organic matter was obtained from Dismal Swamp, NC). The equilibrium total arsenic concentrations increased by as much as 10% to 15% in the presence of organic matter. The continuous flow experiments yielded similar results, where total arsenic concentrations were doubled with the addition of organic matter at approximately 1ppm.

With that result, the next phase was to design a capping cell for bench scale studies. Preliminary work with pentachlorophenol illustrated that the breakthrough increased by an order of magnitude when the spiked sediment foc was increased from 0.5% to 2%.

Because the work proposed had been only partially funded (student support for one summer and one semester), the work was discontinued. Had there been further funding the next steps would have involved spiking the soils or the sediments with various organic and inorganic pollutants and then capping the sediments with clean soil with various organic contents. The release of the contaminant could then be monitored in the water column. A goal of the work was to conduct some of these tests on the geotechnical centrifuge, and a part of that work would have been a determination as to whether the chemical processes were fast enough that time could be correctly modelled in the centrifuge model tests.

DAAG-55-98-10066

All purchases and installations are complete on this facilities upgrade. This has resulted in a data acquisition (DAQ) system that is significantly more sophisticated than originally envisaged when the award proposal was written in 1997, although its installation involved substantial delays. Integration of a LabView Data Acquisition Sytem has required a very substantial input of time to adapt it to this system, however, the program has now been fully incorporated. It has not been necessary to purchase a new detonator box as originally proposed – funds for that were taken from another research contract – and this has freed up the additional needed funds for the more comprehensive data acquisition system. The cone penetrometer is fully operational. The new centrifuge slip rings have been installed on the centrifuge to expand its data transmission capabilities. Miscellaneous accessory equiomemt identified in the original proposal has also been purchased and installed. The cumulative result of the DURIP grant is a very much more powerful centrifuge research facility.

5. Technology Transfer:

There were frequent discussions regarding research between CRREL and WES engineers regarding the frost heave research, including were visits to the CRREL labs at the initiation of the research, and two organized by Dr. Russell Harmon in 1998 and 2000. There was interaction with CRREL researchers through technical committee activity at the annual National Research Council Transportation Research Board Meetings. CRREL assisted in the selection of the natural Fort Edwards clay for this research, and its shipment to the University of Maryland. CRREL has also assisted by making available a numerical model of frost heave that is under development, and may be more suitable for predicting heave in clays.

In pursuing the dioxin contaminant research, we visited with Richard Ledbetter and Michael Palermo of the ERDC-WES laboratory, and maintained contact with them until they concluded that they had not been successful in construction of a working centrifuge sediment capping apparatus

In developing the data acquisition system for the centrifuge, the input from WES centrifuge DAQ designers was invaluable.